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SCIENCE UNCOVERED

FERMILAB ADVANCES NEW CAVERNS AND TUNNELS IN SOUTH DAKOTA

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CUTTING EDGE ROUNDUP

STRONG PROGRAM IN DENVER, CALL FOR PRESENTATIONS FOR LOS ANGELES IN 2016

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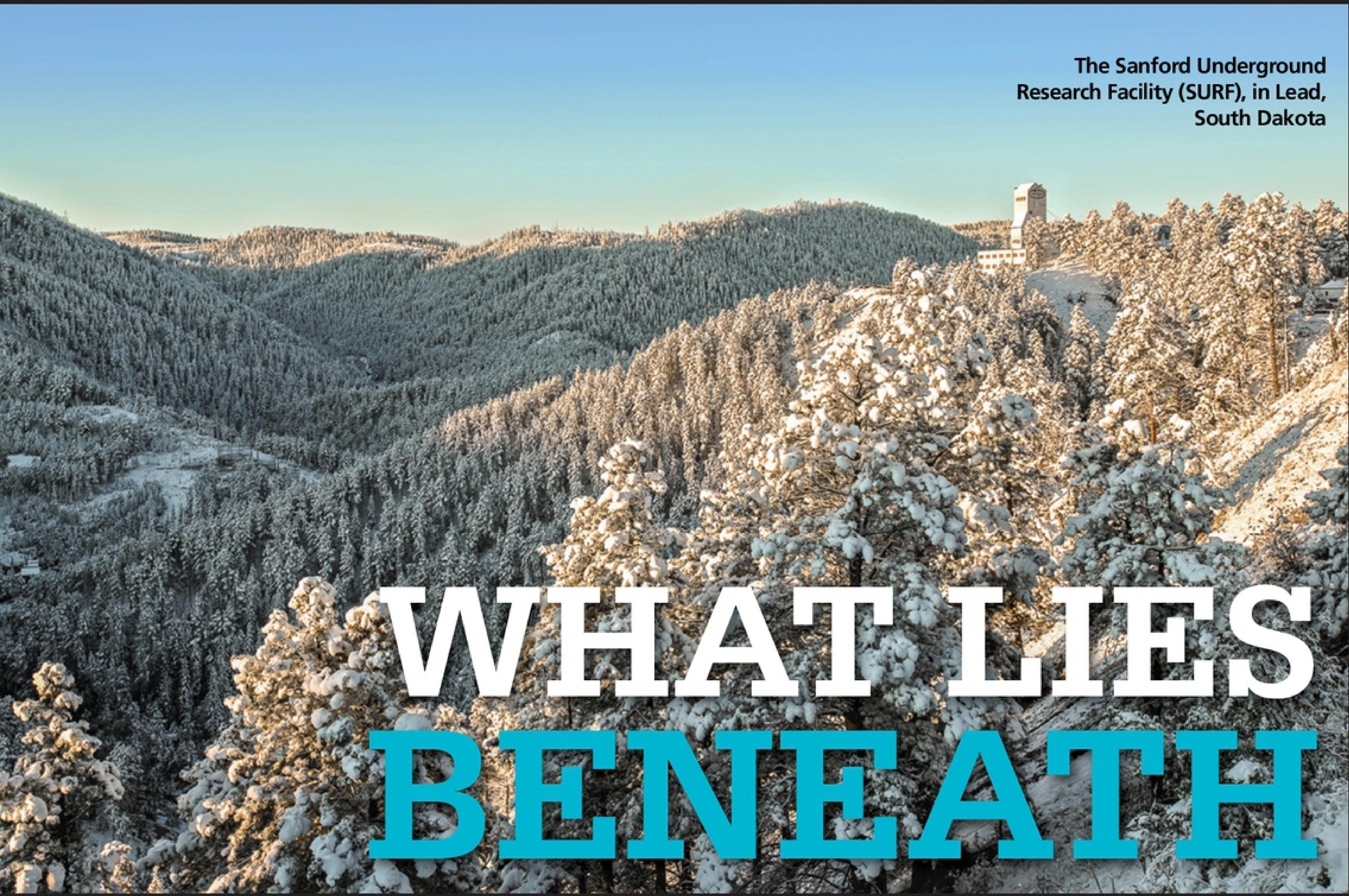
DETECTION & PREVENTION

IN THIS MONITORING ROUNDTABLE NATJ LOOKS AT THE STATE OF THE INDUSTRY



The Sanford Underground Research Facility (SURF), in Lead, South Dakota

WHAT LIES BENEATH

The SURF West Drift, known as the Vent Drift during Homestake days

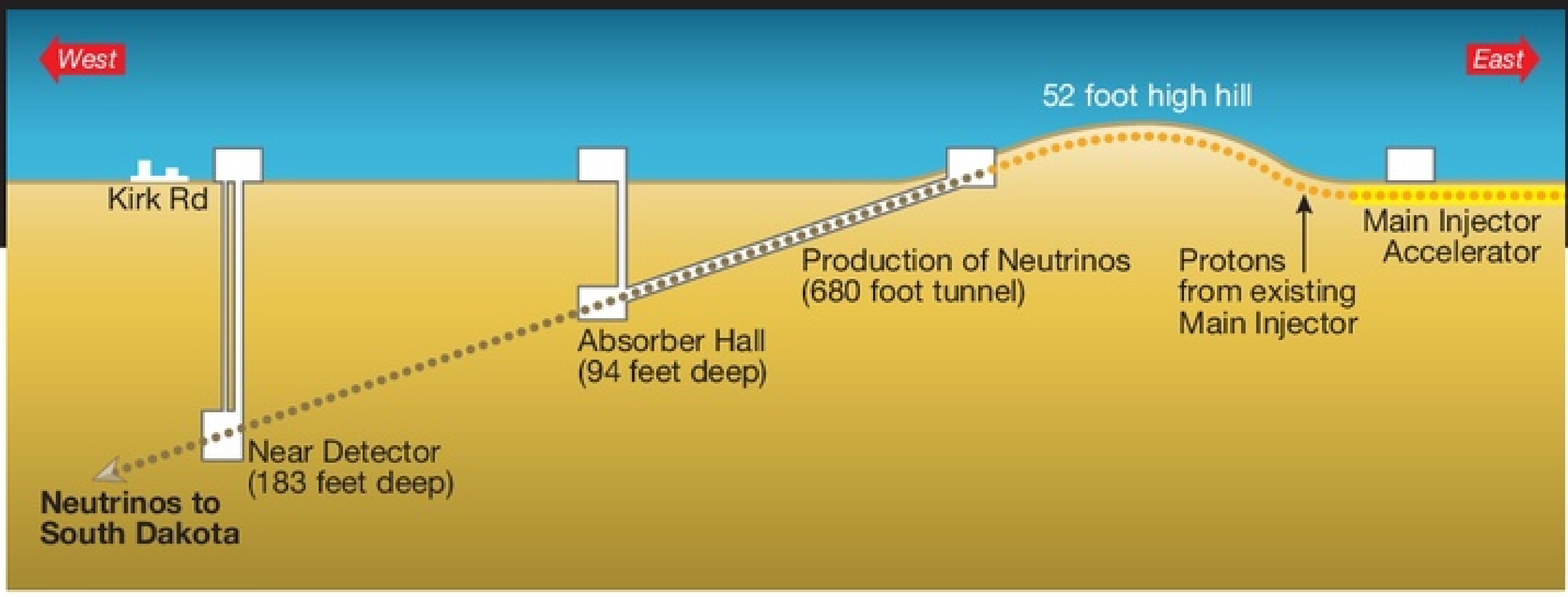
Scientists and civil engineers are coming together one mile beneath the surface in Lead, South Dakota, to create caverns and tunnels for a very special experiment. Kristina Smith spoke to members of the project management team to find out more

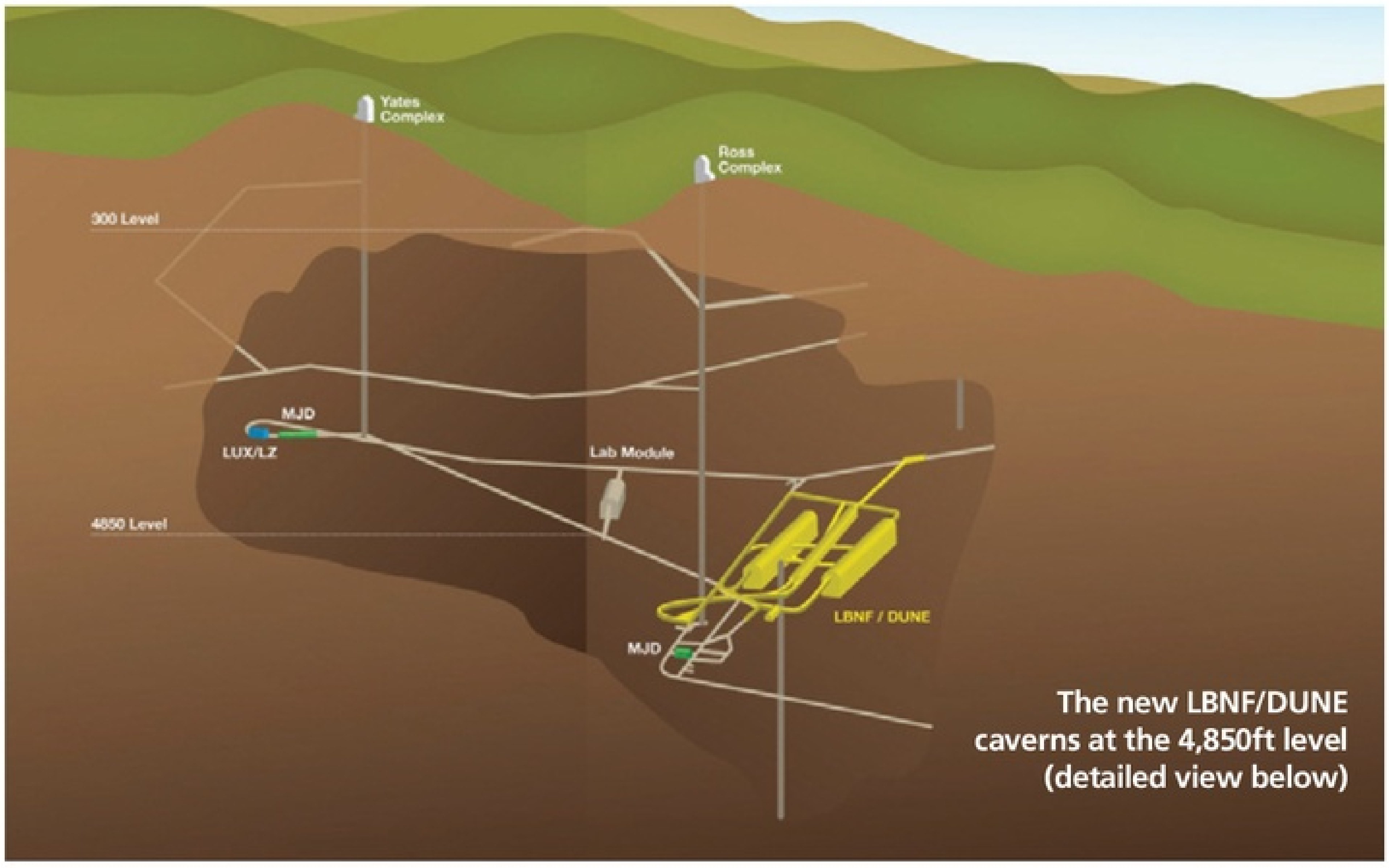
IT SOUNDS LIKE a scene from a James Bond film: descending 4,850ft (1.5km) through the shafts of a disused gold mine to find an world of shiny-floored laboratories, manned by people in white overalls and face masks. These are not the henchmen of a power-hungry villain, but scientists working at the Sanford Underground Research Facility (SURF), which now occupies part of the former Homestake Gold Mine, in Lead, South Dakota.

In ten years' time, this underground lab will also be home to a ground-breaking project that hopes to shed light on the mysterious particles known as neutrinos (see box on p12). The Deep Underground Neutrino Experiment (DUNE) will see high-intensity beams of neutrinos fired 800 miles (1,300km) through the earth's crust from Batavia, Illinois, to detectors at Lead.

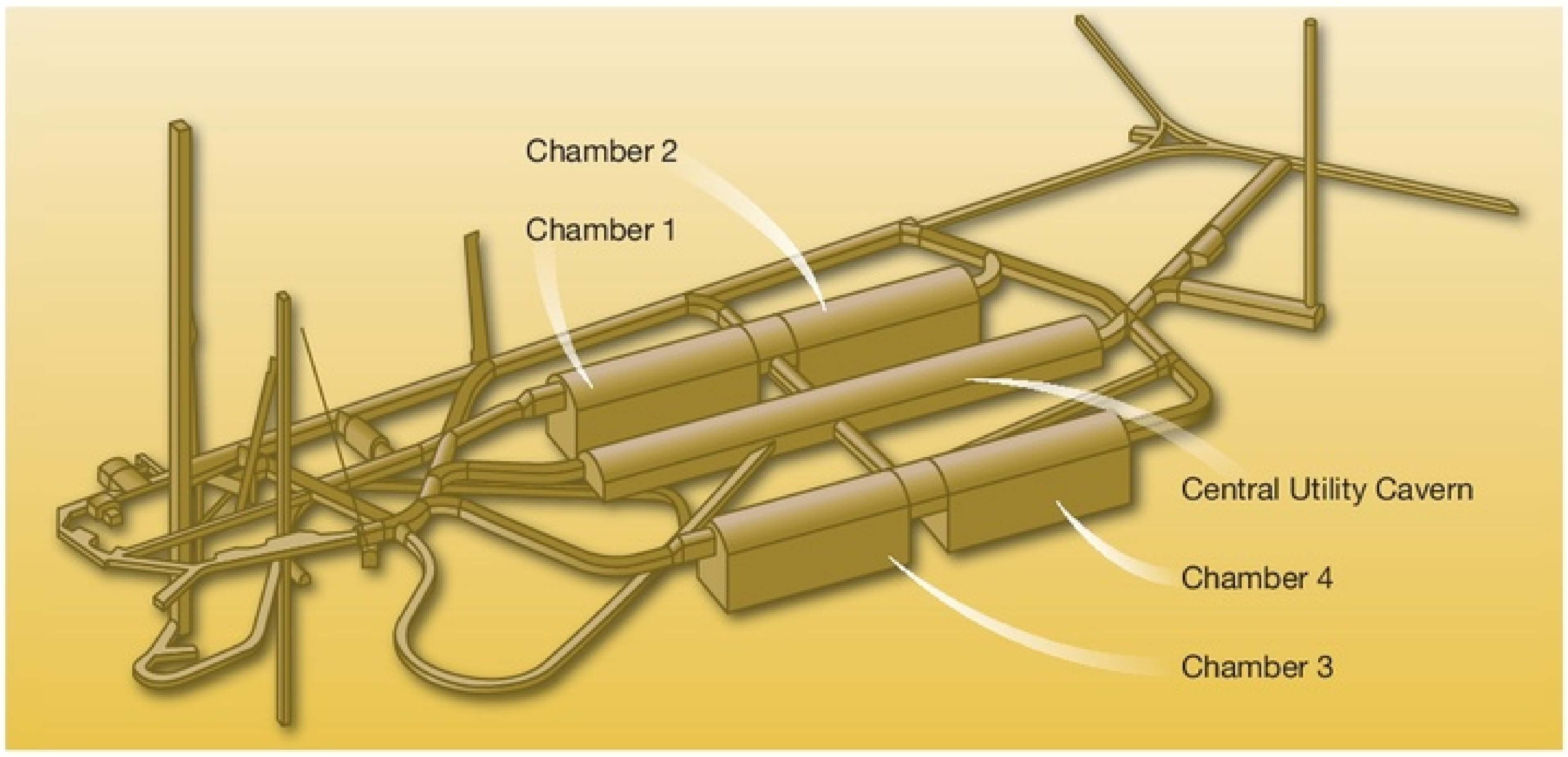
This is an international effort, bringing together some of the world's best minds in particle physics. It will also be the first time that the US has hosted a truly international mega-science project on home soil. Understanding neutrinos could help scientists learn more about the origins and evolution of the universe. It could also help answer questions about matter versus antimatter or to witness the birth of a black hole.

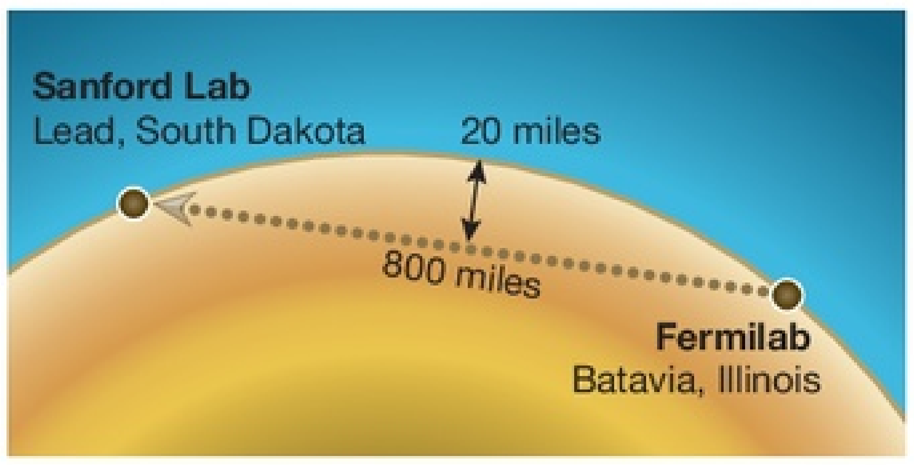
Unfortunately, the neutrinos won't need a tunnel to make their 800-mile journey. However, there are significant underground works required, mostly at the South Dakota site where the cost of construction works is currently estimated at between $250 and $350 million. The Fermi National Accelerator Laboratory (Fermilab), based in Batavia, is leading the project to create the facilities for DUNE, known as the Long Baseline Neutrino Facility (LBNF) project on behalf of the





The new LBNF/DUNE caverns at the 4,850ft level (detailed view below)





Department of Energy. The Fermilab project team intends to procure the construction of the facilities in Lead using a Construction Manager/General Contractor (CM/GC), which will allow the constructors to have input into buildability, materials selection and logistics during upcoming final design stages.

"By using the CM/GC delivery method, our hope is that the CM/GC that we bring on during design will be in a position to self-perform at least part of the work, hopefully the excavation work that represents the largest percentage of the conventional facilities cost by far," says LBNF Conventional Facilities Project Manager Tracy Lundin.

Though the structures themselves are not unusual, their depth beneath the surface and their proximity to ongoing, and highly sensitive experiments is. Bidders will need know-how from both the tunneling and mining worlds and the ability to grasp something of what the physicists are trying to achieve. "In my experience, the challenge is how to get the civil engineer to understand just enough of the science to be able to ferret out what's important to the science community and how to transpose that into the civil engineering world," says Lundin.

The Homestake Gold Mine was North America's largest and deepest gold mine and over its lifetime produced more than 40 million troy ounces (1.25 million kg) of gold. Its other claim to fame is that Dr Raymond Davis Junior built his Nobel Prize-winning neutrino experiment there in 1965.

Having produced its first gold in 1878, the mine closed in 2002, and in 2006 was donated to the State of South Dakota by its owner Barrick Gold Corp. The State developed the level of the mine 4,850ft down into the Sanford Underground Research Facility (SURF).

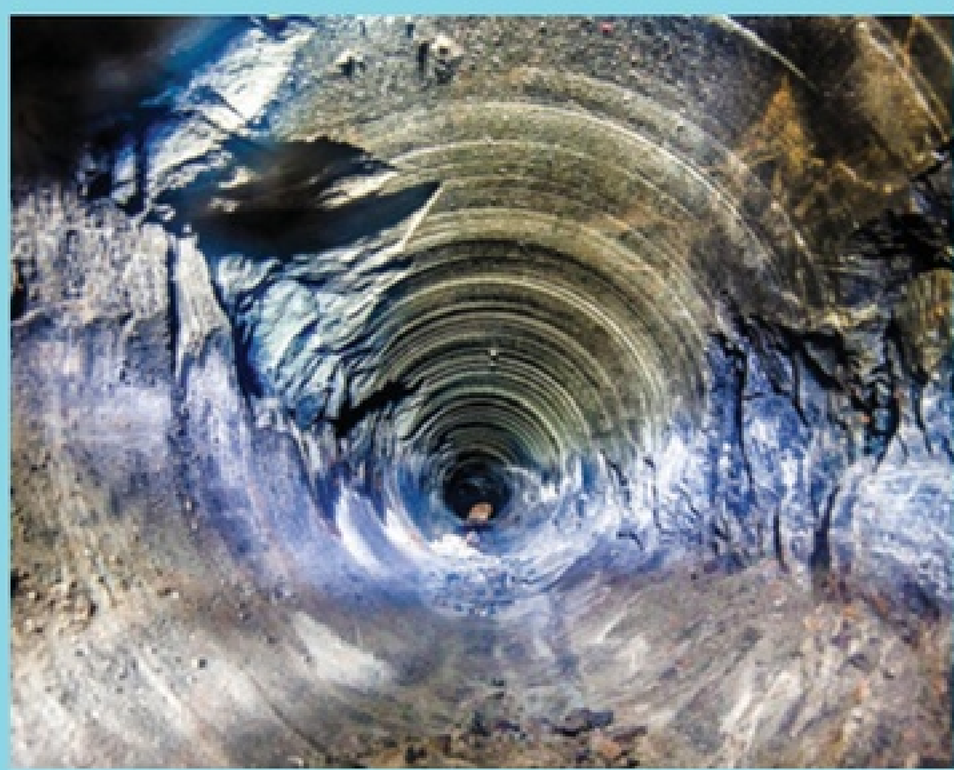
While Davis' work focused on detecting neutrinos made by the sun, DUNE will be working with neutrinos created by Fermilab's existing particle accelerators. A new beamline in Illinois will steer protons from the accelerator upwards and then down into the earth, smashing them through graphite to ultimately create the neutrinos.

Construction of the facilities in Illinois will see around 1,670ft (0.5km) of beamline constructed by cut and cover methods at depths of between 33ft (10m) and 98ft (30m), together with large reinforced concrete structures on the surface, an underground cavern in rock and two vertical shafts around 213ft (65m) in depth. Having travelled the 800 miles to Lead, the neutrinos will be

The Majorana Demonstrator detector strings are so sensitive they must be assembled in nitrogen-filled glove boxes

The world's purest copper is being "grown" in a clean room at the 4,850ft level to make parts for the Majorana Demonstrator

UNDER PRESSURE: THE CHALLENGE OF DESIGNING AT DEPTH BY SETH POLLAK



What makes this project geotechnically unique is its depth. Being a mile underground presents both design and logistical challenges. During the early stages of the site investigation, we aimed to characterize the ground behaviour from both laboratory and in situ tests.

The two main caverns, each housing two liquid argon-filled detectors, a central cavern for utilities and a network of supporting drifts will all be located 4,850ft (1.5km) below ground level. The rock in this area had not been previously characterised in the laboratory, though the fact that it is bounded on three sides by existing drifts from the mine gave us relatively easy access.

The rock around the former Homestake Gold Mine is mainly foliated schist. However, there are also some areas cut through by rhyolite dykes, which are chiefly composed of the same elements that make up glass. This gives the rock a more brittle behaviour, which is not accommodating to large excavations at depth.

Site investigation involved two main activities: mapping several thousand feet of existing mine drifts and continuously coring four sub-horizontal boreholes to cover the proposed cavern location. The mapping and drilling not only allowed us to take a good representation of samples to be tested, but also gave us confidence in locating the caverns to avoid large concentrations of the rhyolite.

The existing drifts were also laser scanned during the site investigation. Laser scanning – taking a 360 degree image of the tunnel by creating a digital point cloud surface – was particularly useful in incorporating accurate geometries of the existing conditions into CAD and numerical models.

The planning, execution and testing related to the boreholes took eight months in all, including two months of almost continuous drilling. When testing on the core samples began in the laboratory, the results were initially surprising: the rock was exhibiting lower strength and stiffness than expected. Our hypothesis was that, because the cores had been removed under such high stresses, the process of removing them caused the rock to relax and develop micro-fractures. To further investigate, we carried out a series of back-analyses that looked at existing examples of ground behaviour and conditions around the mine.

Beginning with the lab data in the model, we were able to show that the in situ rock was in fact stronger than suggested by the testing. For example, 3D models of mine drifts suggested substantial yielding when in fact none was historically observed.

The result of this calibration exercise was significant in developing a realistic representation of the in situ stress and rock mass strength conditions. We were able to reduce preliminary support estimates, swapping 10m long cable bolts for shorter (6m long) rock bolts. The bolts are intended to be permanent support; with a 50-year design life.

An existing ground water pumping system in place at the mine keeps the water level around 1,000ft below the 4,850 Level. Therefore, no cast concrete lining is required, and only a thin (4in thick) layer of shotcrete will be applied to the surface.

With the preliminary design now complete, we look forward to progressing into final design. This is a one-of-a-kind job: there's no other project like it in the world today and it's an amazing endeavour to be involved in.

Seth Pollak, an Associate with Arup, is working on the excavation design of the Long-Baseline Neutrino Facility (LBNF) project at the South Dakota site.

captured by detectors consisting of four massive 17,000 ton tanks filled with argon. The argon will be kept in liquid form using cryogenics, which requires its own network of supply tubes and ground level equipment.

As well as the main caverns, which will be 90ft (27.4m) high by 65ft (19.8m) wide and 505ft (153.9m) long, the underground works will also include a central utility cavern that will be 38ft (11.6m) high by 64ft (19.5m) wide by 624ft (190.2m) long, 3,871ft (1180m) of new or enlarged access 16ft x 20ft (5m x 6m) drifts and 3,125 feet (953m) of mucking ramps.

The preliminary designs for both sites, delivered by Arup supported by McMillen Jacobs Associates and SRK for the South Dakota site and AECOM for Illinois, are now nearing completion, as the project goes through a major review point. However, the nature of this endeavour means that as design of the conventional aspects of the facilities moves on, so do the scientists' designs and requirements for their specialist equipment.

"The scientists are trying to do something with precision and on a scale that's never been attempted in neutrino physics before," explains Christopher Mossey, LBNF Project Director. "The massive detectors are pushing the state of the art in many ways. Our challenge is ensuring that we fully understand and support their requirements as they develop and refine better schemes to detect the neutrinos."

There is an international cast of

Top: The Davis Cavern on the 4,850ft level was once home to Ray Davis' Nobel Prize winning solar neutrino experiment. The cavern is being enlarged to house the LUX experiment
Above: Ground support at the CASPAR site

Rock support at the CASPAR site

SEVEN THINGS YOU MIGHT NOT KNOW ABOUT NEUTRINOS

1. They are tiny particles with no charge
2. They are everywhere, whizzing through your body as you read this
3. No one knows what they weigh – at least a million times less than an electron
4. There are three types: electron neutrinos, muon neutrinos and tau neutrinos
5. Neutrinos transform between types during long journeys in a process called neutrino oscillation
6. The sun produces lots of them, the earth produces them too
7. Scientists use particle accelerators to make them

organisations and individuals working on DUNE; at the last count there were 150 institutions from 26 countries. This is par for the course in this field, says Mossey: "The requirements to make the next discovery in particle physics have progressed to the point that no longer can one university, one laboratory, or even one country do it by themselves... you need to pull together scientists and support from around the world," he says. "That's how CERN [where the Large Hadron Collider is located, in Geneva] operates and that's how things here will operate. It is extraordinarily complex and requires the efforts of many talented people."

These scientists are represented by a body called the DUNE Collaboration. "The Collaboration simplifies our work by narrowing down the discussions on interfaces and requirements," says Lundin.

In delivery, the biggest challenge will be the logistics. There are two entrances to SURF, the Ross Shaft and the Yates Shaft, which the constructor must share with ongoing experiments, and those installing the systems and equipment needed for DUNE.

Arup is nearing completion of a logistics study that has involved multi-stakeholder workshops to try and understand who will need what when. "The logistics study will be a large cornerstone as to how we execute this," says Lundin. "The logistics component is the main reason why having the CM/GC on board during design is going to be critical."

The current plan will see rock from the drill and blast excavation transported by skip up the mine's Ross Shaft, which is currently undergoing a refurbishment. From there, the thinking is that it will travel by conveyor to another former mine.

The other element that those constructing the shafts and drifts must take into account is the neighbouring experiments. Among those currently underway are the Large Underground Xenon (LUX) experiment, a detector looking for dark matter; the Majorana Demonstrator project, which is searching for something called neutrinoless double-beta decay; and CASPAR (Compact Accelerator System for Performing Astrophysical Research), which will mimic nuclear fusion reactions in stars.

In practice, this could mean that blasts have to be carefully designed in order to limit vibration and air overpressure effects. This could have an impact on production rates, and is another area where CM/GC expertise will come into play.

There is a big caveat to all these plans: securing the necessary funding is not always easy and other similar projects have fallen by the wayside over the years. Plans for a Deep Underground Science and Engineering Laboratory (DUSEL) at the Homestake Mine site were a few years in when funding was withdrawn in 2010.

A large proportion of the funding for both LBNF and DUNE is planned to come from the Department of Energy. "We are working through a variety of critical approval milestones, but we are confident and on-track," says Mossey. International partners, including CERN, have already indicated plans to support critical elements such as detectors, cryostats, and cryogenic systems.

Assuming that things do run to plan, the schedule for LBNF will see detailed design begin in 2016 with a completion date of early 2017, when FermiLab will advertise for a CM/GC. Construction could then begin in 2018 and run for around four years. There are already some details of the contract on the FedBizOps.gov website and the project team hope to release a Request For Proposals before the end of this year.

The LUX dark matter detector under construction at SURF's surface laboratory

As for the DUNE itself, it may be 2024 or 2025 before scientists can start to collect the data, although some preliminary research, looking at neutrinos from the sun rather than from the accelerator beam could begin a couple of years earlier. A decade isn't long to wait when you're a particle physicist, says Mossey: "Physicists can devote almost a career to a particular question. Ten years is nothing. Given the time scale of the fundamental questions they're trying to answer, it's the blink of an eye."

All photos of the SURF underground facilities and experiments by Matt Kapust.